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THREE-WAY DOPPLER TRACKING RESULTS FOR USE IN THE PRELIMINARY DISPERSION ANALYSIS OF THE LUNAR LANDING MISSION

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PROJECT APOLLO

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SUMMARY AND INTRODUCTION

The tracking results calculated for use in the first preliminary dispersion analysis for the lunar landing mission are presented in this paper. Only the CSM activities for the translunar and transearth portions of the mission were analyzed.

Since the 3-way Doppler tracking capability had not previously been checked out in the program used (i.e., the Tracking Accuracy Prediction Program (TAPP IV); see ref. 1), the Mathematical Physics Branch (MPB) specified that the translunar and transearth phases be simulated using only 3-way Doppler information. The model used in this study, therefore, is not the one currently planned for the lunar landing mission, but is conservatively representative.

The MPB has agreed to the validity of the data presented. Mr. L. K. Paul and Mr. V. G. Schock of TRW Systems helped acquire and compile this data.

The cross correlation effects were also calculated and may be obtained from the author.

ANALYSIS

Tracking Model

For the 3-way Doppler tracking, two slave stations were assigned to a particular master and served only that master during the mission. The tracking was performed by the following three master-slaves combinations:

Master Stations	Slave Stations
Madrid	Ascension, Bermuda
Goldstone	Hawaii, Grand Bahama
Canberra	Carnarvon, Guam

Tracking "overlaps" were eliminated by splitting the overlap time between two master stations. The only tracking data simulated was range rate, which was sampled every 60 seconds. Station location uncertainties (longitude, latitude, and altitude) were correlated on a pass-to-pass basis; data biases were not correlated. A reduced value was used in modeling the data bias errors under the assumption that three-way biases would be computed during real time. No a priori tracking knowledge was assumed after a maneuver was executed.

A period of free flight preceded each of the following events, and uncertainties were calculated just before each using the tracking during the free-flight period:

1. The first midcourse correction
2. The second midcourse correction
3. The LOI burn
4. The TEI burn
5. The third midcourse correction
6. The fourth midcourse correction

Tracking started immediately following an event and was stopped approximately 1 hour before a maneuver execution except for the first midcourse correction and the TEI burn. In these two cases it stopped 30 and 50 minutes, respectively, before the events. In no case was tracking simulated when the elevation angle from the local horizontal was less than 5°.

Table I lists start, stop, and elapsed tracking times for each of the master stations for the above events. The time is measured from translunar injection.

Generation of Data

The TAPP IV program was used to generate the normal matrices of the deviation in tracking due to error in the station location based on the lunar landing mission preliminary reference trajectory (ref. 2). A tape was generated for each master station and its slaves tracking during the mission. Three TAPP IV tapes were required for the complete analysis. A series of programs called FASTAP I, II, and III sequence, edit, and merge the data necessary to provide a quick look at navigation results and provide input into the analytic prop boxes (which simulate the mission segments) of the Monte Carlo Dispersion Analysis Program, TAPP VI, (ref. 3). This tape was then used as input to the FASTAP II program, which generated the TAPP VI input tape containing the free-flight and powered-flight matrices necessary to run the complete lunar landing mission preliminary dispersion analysis and which also provided a tape for FASTAP III. The FASTAP III program was then used to compute the statistics needed to represent the navigation model. The results given are those obtained from the FASTAP III program.

The uncertainty in the CSM state vector considers the noisy tracking, the dynamic systematic errors (uncertainty in the earth's gravitational constant and the moon's gravitational constant) and the nondynamic systematic errors (tracking station location uncertainties and tracking biases).

RESULTS AND CONCLUDING REMARKS

The 3σ uncertainties in the CSM state vector are presented for three coordinate systems - the XYZ earth-centered inertial system, a spherical system, and a UVW system. In the UVW system, U is in the radial direction, V is downrange, and W is crossrange.

The 3σ uncertainties for position and velocity in the UVW and ECI coordinate systems are tabulated in tables II and III, respectively. The 3σ uncertainty in spherical coordinates are tabulated in table IV.

The model used in this study will not be used for the lunar landing mission, but it will be used for the preliminary dispersion analysis. Since only 3-way Doppler information was used, the uncertainties presented are conservatively representative.

TABLE I.- TRACKING FOR MANEUVERS DURING THE TRANSLUNAR AND TRANSEARTH PHASES OF THE LUNAR LANDING MISSION

Master tracking station	Start, hr:min:sec from TLI	Stop, hr:min:sec from TLI	Interval, hr:min:sec	Event
Goldstone	1:01:40	2:30:00	1:28:20	Midcourse 1[a]
Goldstone	3:03:20	9:30:20	6:27:00	Midcourse 2[b]
Canberra	9:30:20	16:11:40	6:41:20	
Madrid	16:11:40	26:12:40	10:01:00	
Goldstone	26:12:40	33:51:40	7:39:00	
Canberra	33:51:40	40:45:40	6:54:00	
Madrid	40:45:40	50:26:10	9:40:30	
Goldstone	50:26:10	58:12:20	7:46:10	
Canberra	58:12:20	59:59:52	1:47:32	
Canberra	61:00:00	64:58:40	3:58:40	LOI Burn[b]
Madrid	64:58:40	73:09:05	8:10:25	
Canberra	108:14:49	108:24:49	10:00	TEI Burn[c] (Tracking around moon)
Canberra	109:10:49	110:27:49	1:17:00	
Canberra	111:12:49	112:29:49	1:17:00	
Canberra	113:14:49	113:53:09	38:20	
Madrid	113:53:09	114:31:29	38:20	
Madrid	115:15:29	116:14:49	59:20	
Madrid	117:06:48	123:39:18	6:32:30	Midcourse 3[b]
Goldstone	123:39:18	130:48:00	7:08:42	
Canberra	131:48:20	137:38:08	5:49:48	Midcourse 4[b]
Madrid	137:38:08	147:41:08	10:03:00	
Goldstone	147:41:08	155:34:08	7:53:00	
Canberra	155:34:08	161:37:38	6:03:30	
Madrid	161:37:38	171:50:08	10:12:30	
Goldstone	171:50:08	179:51:38	8:01:30	
Canberra	179:51:38	185:41:08	5:49:30	
Madrid	185:45:08	194:49:04	9:07:56	

[a] Tracking stopped 30 minutes before the maneuver.

[b] Tracking stopped 1 hour before the maneuver.

[c] Tracking stopped 50 minutes before the maneuver.

TABLE II.- 3σ UNCERTAINTIES IN THE CSM UVW STATE VECTOR FOR THE TRANSLUNAR AND TRANSEARTH MANEUVERS OF THE LUNAR LANDING MISSION

[Three-way Doppler tracking]

Parameters	Uncertainties					
	Midcourse 1	Midcourse 2	LOI	TEI	Midcourse 3	Midcourse 4
U, ft	15 171.12	30 795.12	60 144.60	110.76	209 177.07	40 783.50
V, ft	260 554.92	163 221.92	252 724.26	1047.69	63 750.39	81 608.34
W, ft	153 093.06	151 708.20	187 693.92	6985.74	597 616.71	166 636.38
$\dot{U}$, fps	5.97	0.06	136.17	0.87	4.74	0.18
$\dot{V}$, fps	20.04	0.66	9.81	0.09	1.02	1.11
$\dot{W}$, fps	6.15	0.78	146.40	7.47	9.54	0.99

TABLE III.- 3σ UNCERTAINTIES IN THE CSM XYZ STATE VECTOR FOR THE TRANSLUNAR AND TRANSEARTH MANEUVERS OF THE LUNAR LANDING MISSION

[Three-way Doppler tracking]

Parameters	Uncertainties					
	Midcourse 1	Midcourse 2	LOI	TEI	Midcourse 3	Midcourse 4
X, ft	88 782.12	50 234.34	145 839.27	597.12	160 182.36	80 061.84
Y, ft	206 282.64	131 037.09	248 293.26	2728.54	334 592.80	130 744.26
Z, ft	202 784.94	175 815.90	129 544.47	6489.18	510 452.37	112 191.51
$\dot{X}$, fps	1.89	0.30	107.79	0.45	3.42	0.87
$\dot{Y}$, fps	18.42	0.51	64.23	3.75	6.54	0.66
$\dot{Z}$, fps	11.52	0.84	155.97	6.51	7.74	1.02

TABLE IV.- 3σ UNCERTAINTIES IN THE SPHERICAL-COORDINATES STATE VECTOR FOR THE TRANSLUNAR AND TRANSEARTH MANEUVERS OF THE LUNAR LANDING MISSION

[Three-way Doppler tracking]

Parameters	Uncertainties					
	Midcourse 1	Midcourse 2	LOI	TEI	Midcourse 3	Midcourse 4
Longitude, deg	0.078	0.006	2.643	0.003	0.048	0.012
Geodetic latitude, deg	0.072	0.009	1.215	0.066	0.183	0.015
Radius, ft	15 213.57	30 792.00	58 248.18	123.84	208 959.42	40 766.49
Inertial azimuth, deg	0.03	0.06	1.68	0.09	2.43	0.09
Inertial flight-path angle, deg	0.012	0.006	1.326	0.001	0.009	0.018
Inertial velocity, fps	21.80	1.02	200.18	7.52	10.70	1.49

REFERENCES

1. TAPP IV Program Description. TRW Note No. 67-FMT-477, March 31, 1967.

2. AS-504A Preliminary Spacecraft Reference Trajectory (U), MSC Internal Note No. 66-FM-70. (C), July 1, 1966.

3. Cohen, L. B.: A Description of TAPP VI. TRW Note No. 66-FMT-267, February 24, 1967.